"Application of Optic Flow to Missiles"

by

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for the

Precision Guidance of Small Diameter Missiles Workshop

(Including High Accuracy Non-GPS Guidance)
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? Background - Why investigate optic flow? ? Optic Flow (OF) definition ? Review of current OF efforts ? Specific challenges for missile application ? Goals for AFRL/MN effort

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Overview

- Background - Why investigate optic flow?
- Optic Flow (OF) definition
- Review of current OF efforts
- Specific challenges for missile application
- Goals for AFRL/MN effort

Background

Modern smart munitions typically have two sensors used for guidance:

- IMU (Inertial Measurement Unit)
- Seeker

To make these affordable while still meeting required levels of performance, some tricks are used e.g. low quality IMU can perform adequately if INS solution uncertainty can be bounded. One way to do this is by coupling INS with GPS receiver. However, we are now looking to other sensors to accomplish this same goal.

Why investigate Optic Flow?

- Growing need to mitigate effects of GPS jamming
- OF could be used to bound errors on INS
- OF could be used for target detection
- Part of a larger program (FUSN) seeking to achieve Full Use of Sensors in Navigation

FUSN
(Full Use of Sensors in Navigation)

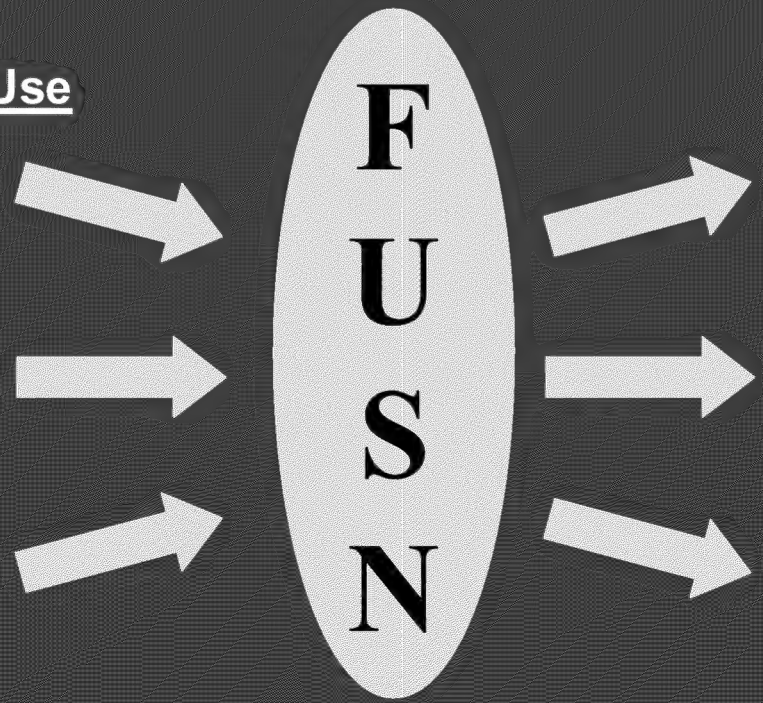
Improving performance by fully integrating all components (seekers, airframe, propulsion, autopilot design, fuzing, warhead, etc.) and fully exploiting all information obtained by each.

Typical Component Use

Navigation:
INS, GPS

Guidance:
INS, GPS, Seeker

Control:
INS, Airframe



FUSN Integration

Navigation:
INS, GPS, Seeker, Airframe

Guidance:
INS, GPS, Seeker, Propulsion, Airframe, Fuzing

Control:
INS, Airframe, Seeker

Defining Optic Flow

a.k.a. structure from motion, visual flow, kinetic depth

What is optic flow?

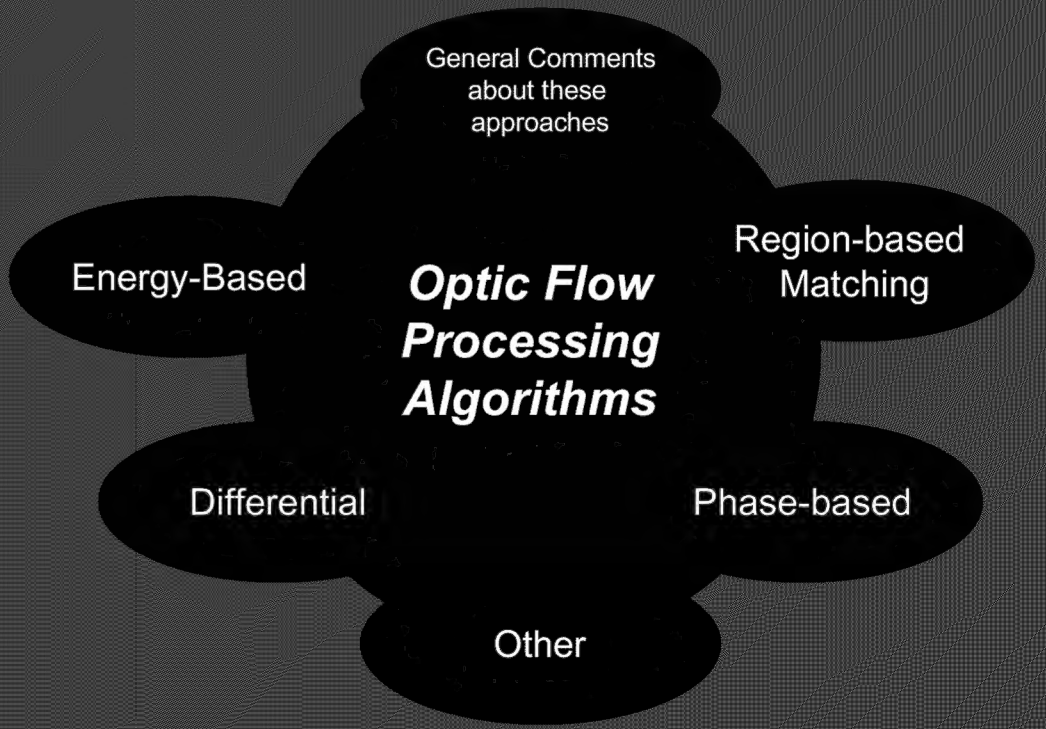
"Opening the eyes of the weapon." The 2 dimensional flow field generated by calculating the velocity field properties (gradient, curl, divergence) of objects/features moving across an image plane.

What is egomotion?

Egomotion is the motion of the observer (camera). It can be extracted from optic flow data when the appropriate conditions & assumptions are satisfied.

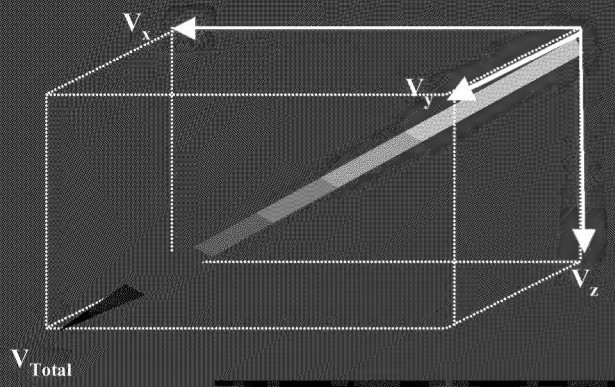
Required assumptions

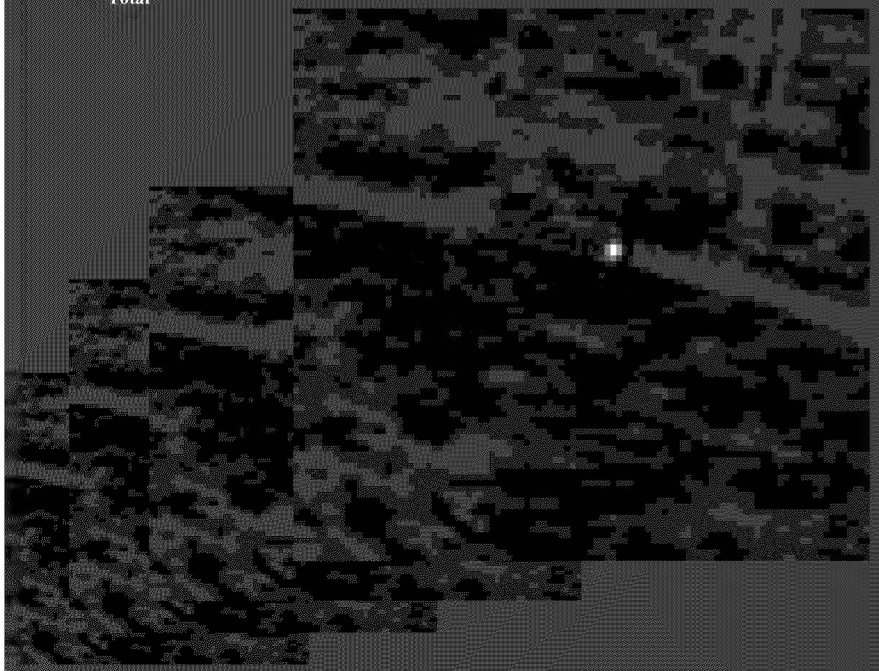
How can we use optic flow to augment guidance and autopilot functions?



OPTIC FLOW

RELATIVE MOTION FROM THE SEEKER





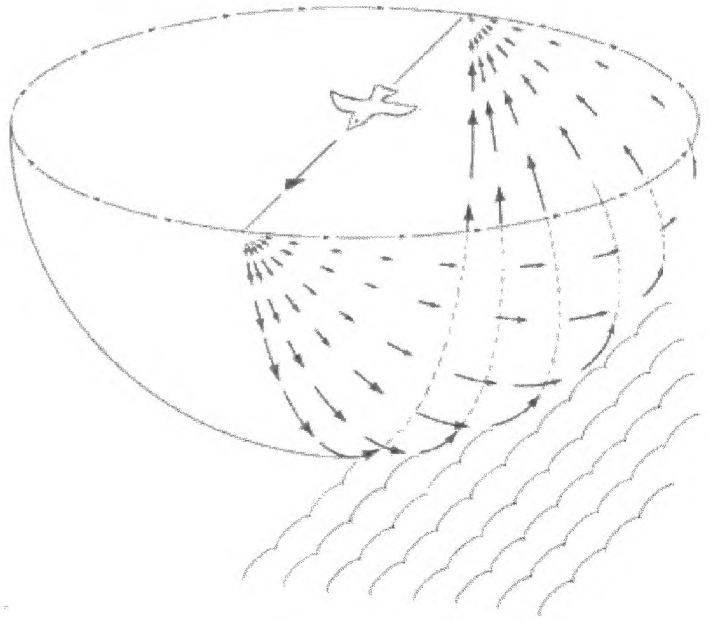


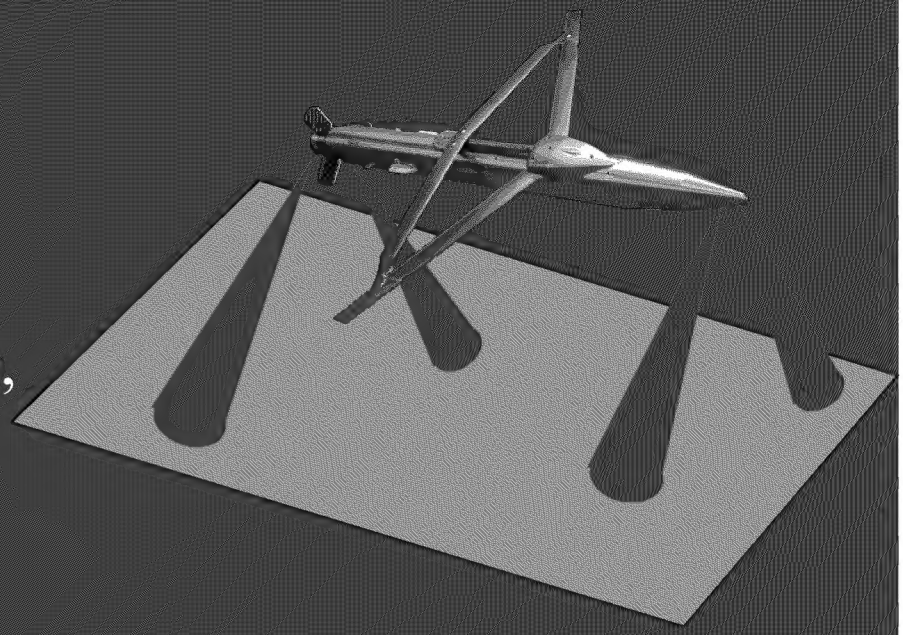
Figure 3–55. Gibson's example of flow induced by motion. The arrows represent angular velocities, which are zero directly ahead and behind. (Reprinted from J. J. Gibson, *The Senses Considered as Perceptual Systems*, Houghton Mifflin, Boston, 1966, fig. 9.3. Copyright © 1966 Houghton Mifflin Company. Used by permission.)

Current Optic Flow Technology

- There are many algorithms available to calculate OF yet very few to turn OF into egomotion
- Roboticists usually solve a 2D egomotion problem…we need the full 3D solution
- Most algorithms use a single forward looking sensor
- Very few demonstrations of useful OF in aircraft/missile applications

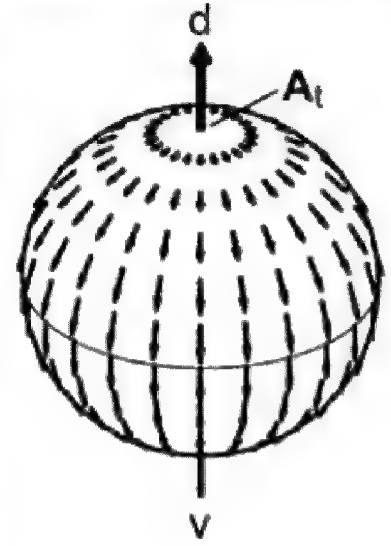
Specific Challenges for Missile Application

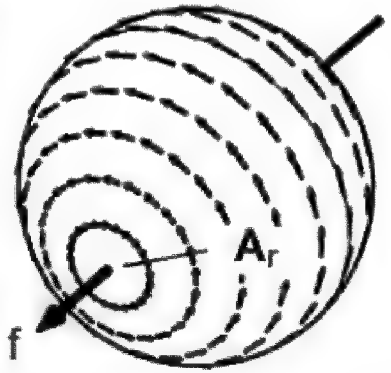
- Need basic research to address:
  - Optimal number of sensors
  - Optimal look directions of sensors
  - Optimal resolution, sampling rate, field of view, wavelength, etc.

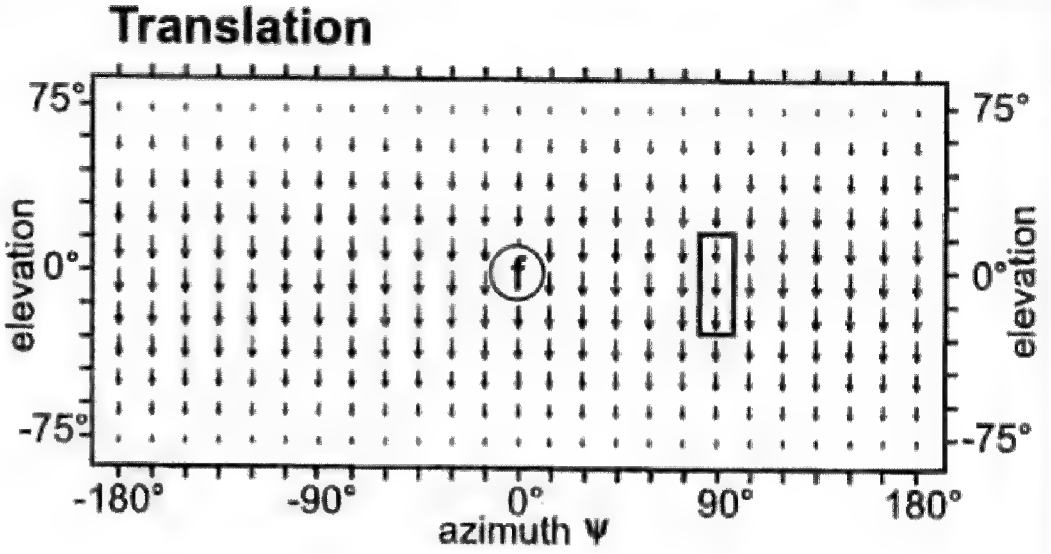


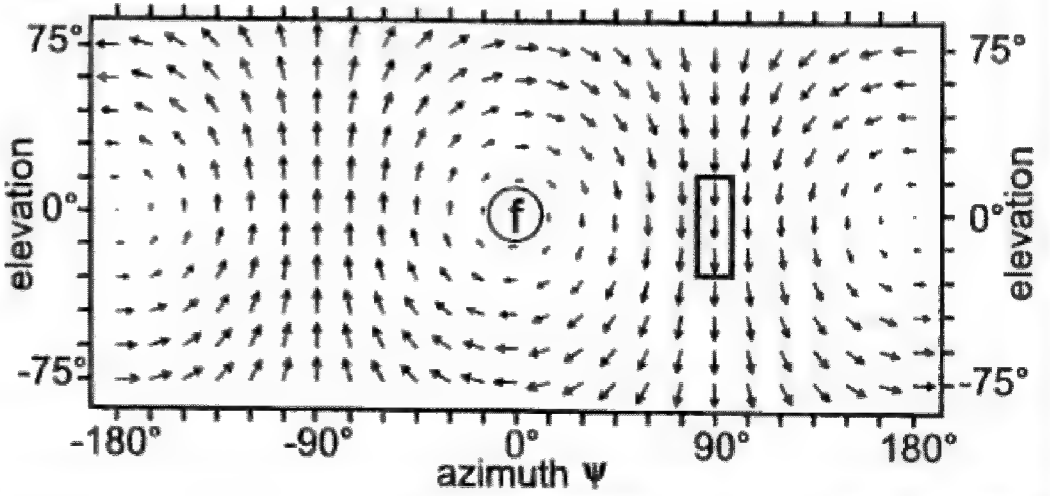
- Issues associated with:
  - Use of OF data within the GNC loops
  - Closed loop stability…what are the requirements on the stability of the OF and egomotion solutions?
  - Frame rates
  - Nonlinearities

Translation and Rotation Can Be Indistinguishable for Sufficiently Small Local Fields







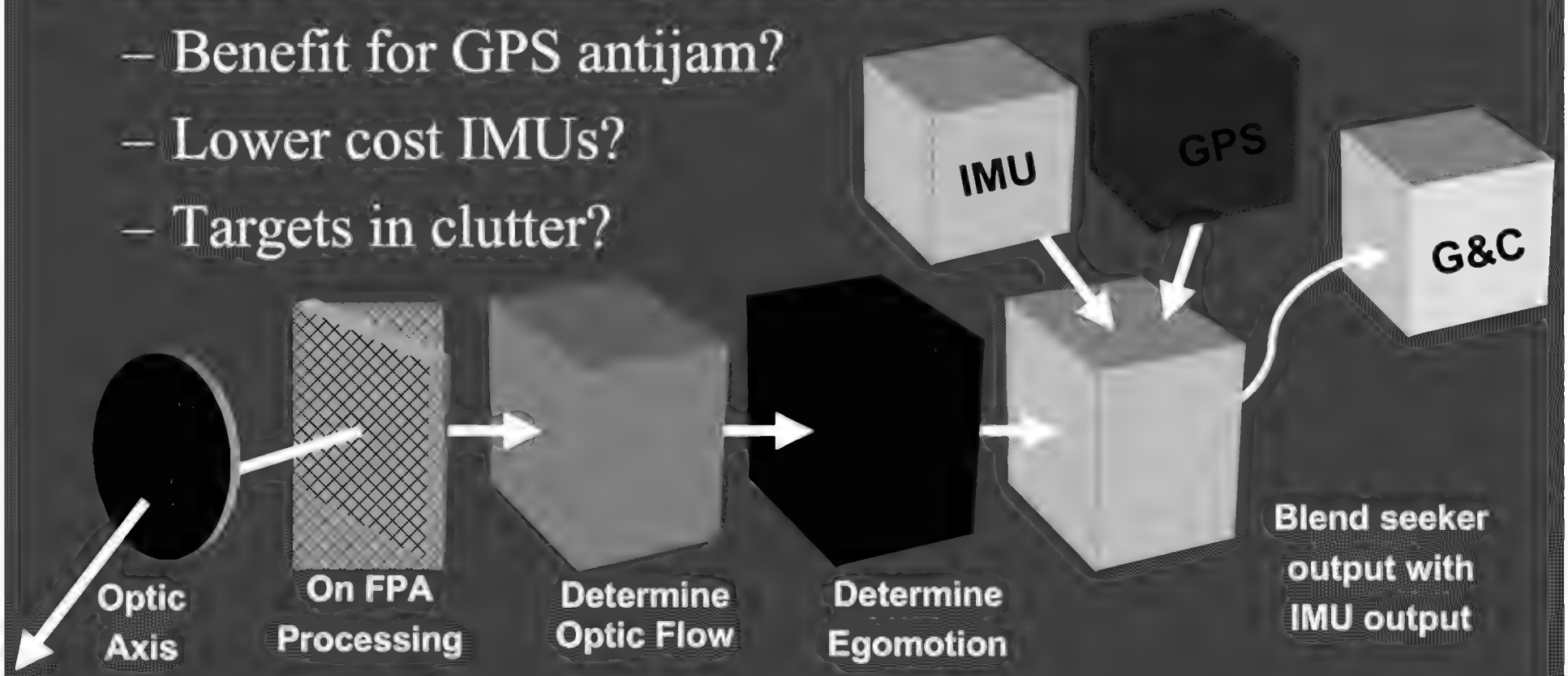


OPTIC FLOW
CURRENT SEEKER OPTIONS

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
• LADAR (SCANNING)	• HIGH SPATIAL RES, 3 D	• WEATHER, SCAN TIME
• FLASH LADAR	• HIGH SPATIAL RES, 3 D	• WEATHER PENETRATION
• PASSIVE MMW IMAGING	• WEATHER PENETRATION	• LOW SPATIAL RESOLUTION, SCAN TIME,COST
• SAR	• WEATHER PENETRATION	• RELATIVELY LOW SPATIAL RESOLUTION, REQUIRED PROCESING LOAD, SCAN TIME, COST
• IMAGING IR	• HIGH SPATIAL RESOLUTION, MULTISPECTRAL	• WEATHER PENETRATION
• VISIBLE	• HIGH SPATIAL RESOL, COTS, LOW COST, MULTISPECTRAL	• WEATHER PENETRATION, ONLY WORKS IN DAYTIME

Goals for the AFRL/MN Research

- Build a testbed to address specific challenges
  - Simulation, Hardware-in-the-loop, flight vehicle
- What is the best way to use the data?
  - Benefit for GPS antijam?
  - Lower cost IMUs?
  - Targets in clutter?



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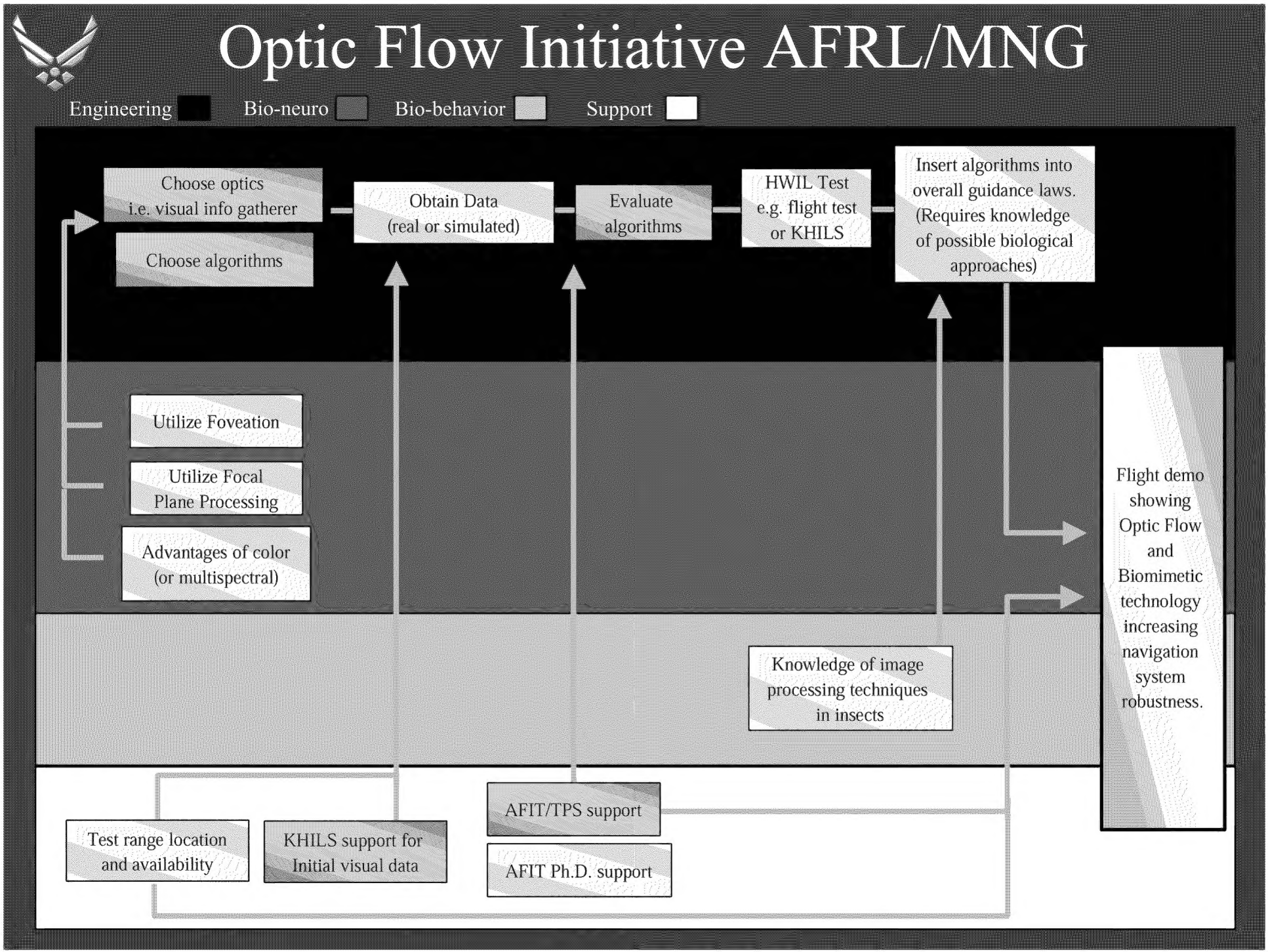
  - Applied Research...where are the existing bottlenecks?

Optic Flow Initiative AFRL/MNG



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  - Applied Research...where are the existing bottlenecks?
- Investigate cooperative benefits of combining MEMs IMUs with near term OF rotational data i.e. MEMS IMUs have a weakness that could be compensated by OF

Current Focus: Looking for technology to mitigate effects of GPS jamming and increase the overall robustness of the GNC system.

Questions?